BISTRO: NGC 2071IR

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NGC 2071IR

- **Massive dense core** with 8 near-infrared objects in the central region (Walther et al. 1993)
- **Bipolar outflow** (Bally 1982; Snell et al. 1984)
- d = 417 $\pm$ 5 pc (adopt the distance of NGC 2068 derived by Kounkel et al. 2018)

- Observation (13.3 hrs)
  - JCMT SCUBA 2 POL-2 polarimeter at **450μm and 850μm** at Band-2 weather
  - DAISY observing mode covering 12' area

- Spatial resolutions: 9.6", corresponding to 4000 AU ($\sim$0.02pc) at 450μm
  14.1", corresponding to 5800 AU ($\sim$0.03pc)at 850μm
- Sensitivity: 20 mJy/beam at 450μm, 1.5 mJy/beam at 850μm

∗ Note: ^{12}CO(3-2) emission (using the HARP archive data) has been subtracted in the 850μm continuum map & 225 GHz continuum from SMA archive data

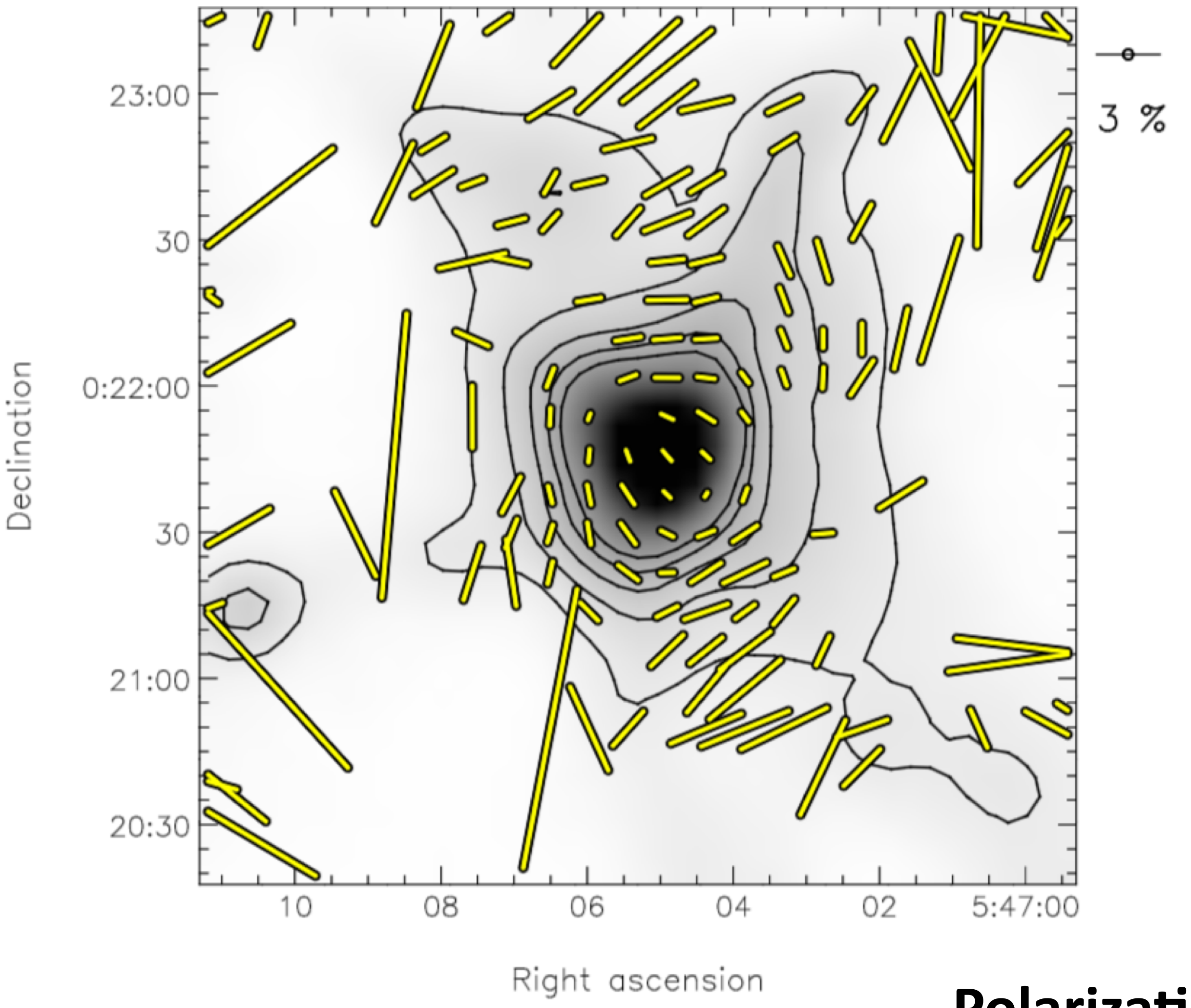
Previous polarization studies

■ Matthew et al. 2002, 2009 using **JCMT SCUPOL**
: **pinched B-field structure at the center**
: B-field strength of **56 μG** using the Chandrasekhar and Fermi method

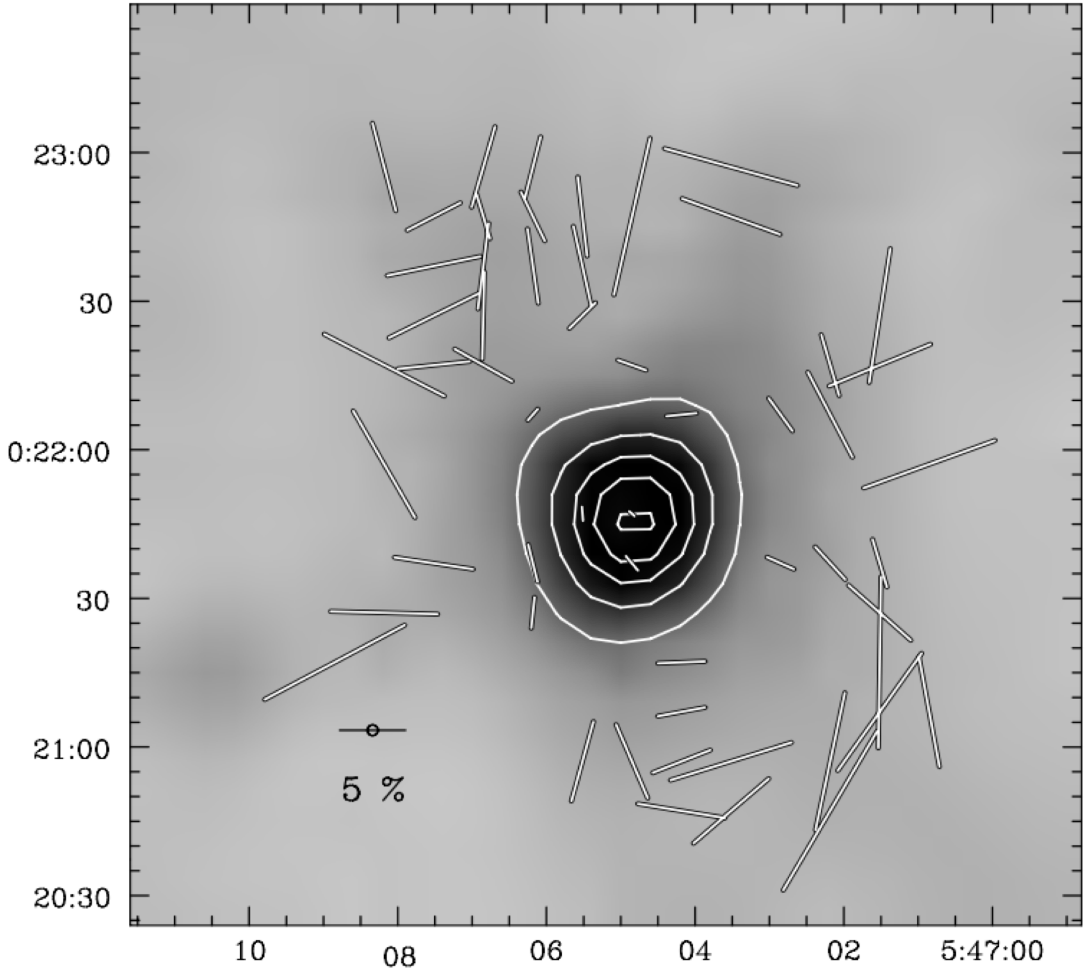
■ Cortes et al. (2006) using **BIMA** with the spatial resolution of about 4 arcsec
: **B-fields in the outflow are parallel to outflow direction** based on $^{12}CO(2\text{-}1)$ line polarization observation

NGC 2071 IR

POL-2 (this study)



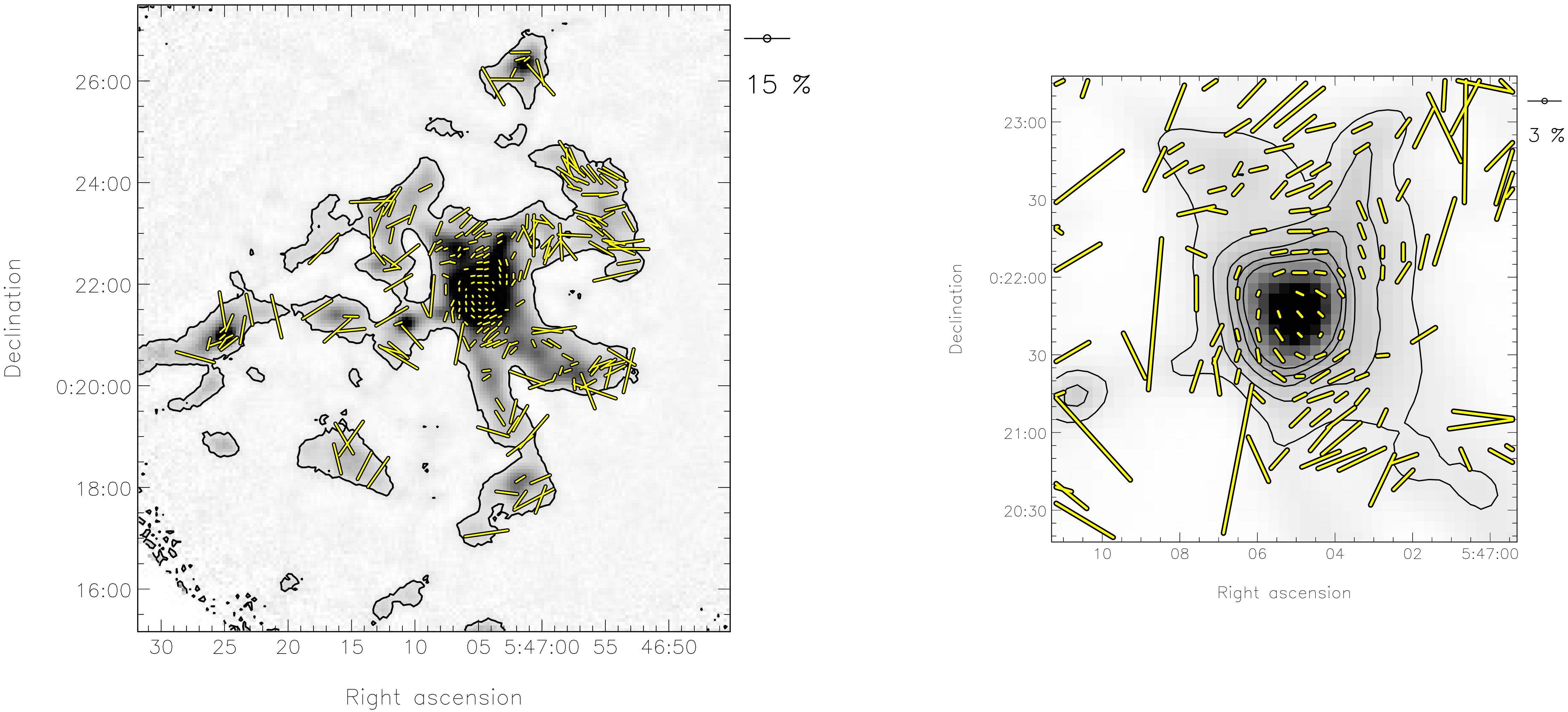
SCUPOL (Matthews et al. 2009)



Polarization Vector

1. Observational results

Polarization vector map at 850μm

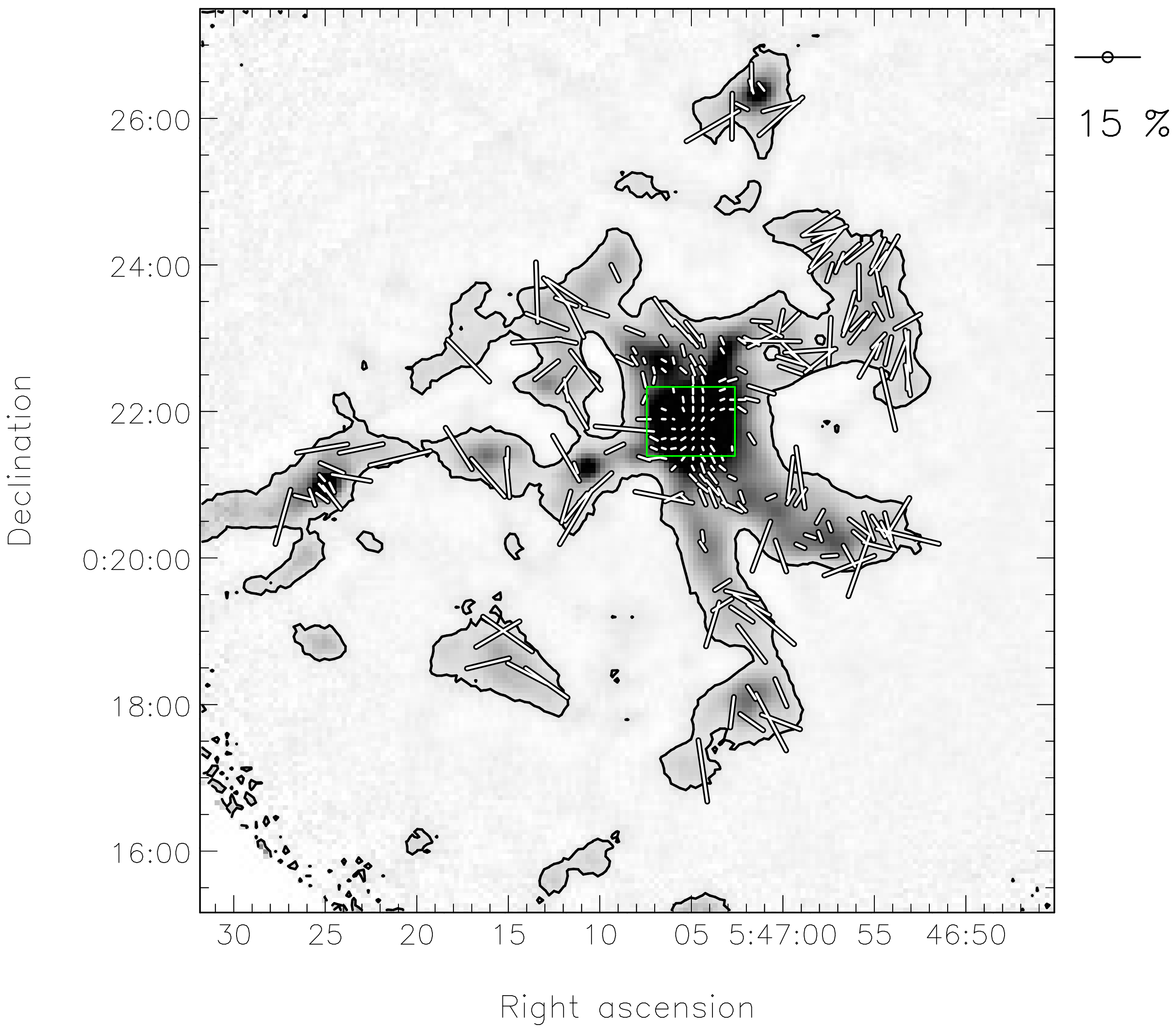


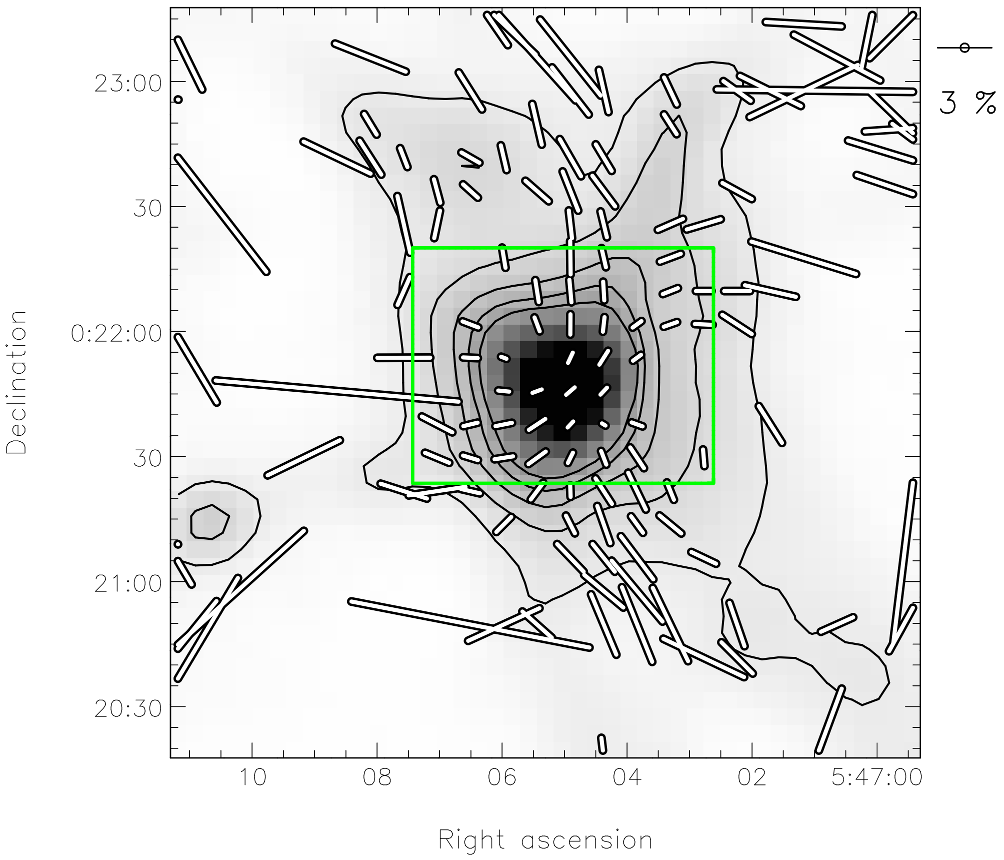
SCUBA POL-2 850μm polarization vectors map of the NGC 2071IR.
Polarization vectors at $(P/\delta P) \geq 3$

1. Observational results

Inferred B-field vector map at 850μm

pinched morphology at the center

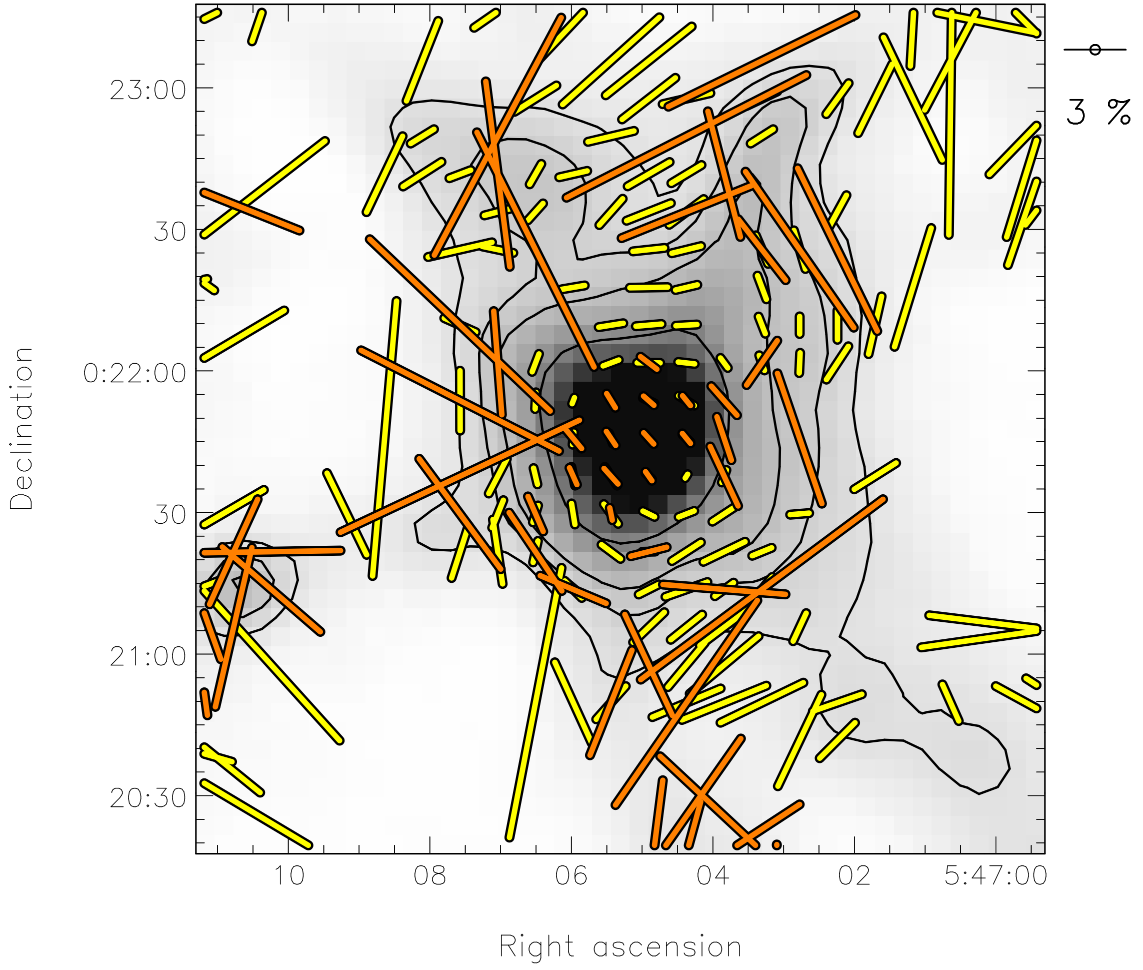




1. Observational results

Polarization vector map at 450/850μm

Good polarization angle agreement in the center region at both 450/850 μm data

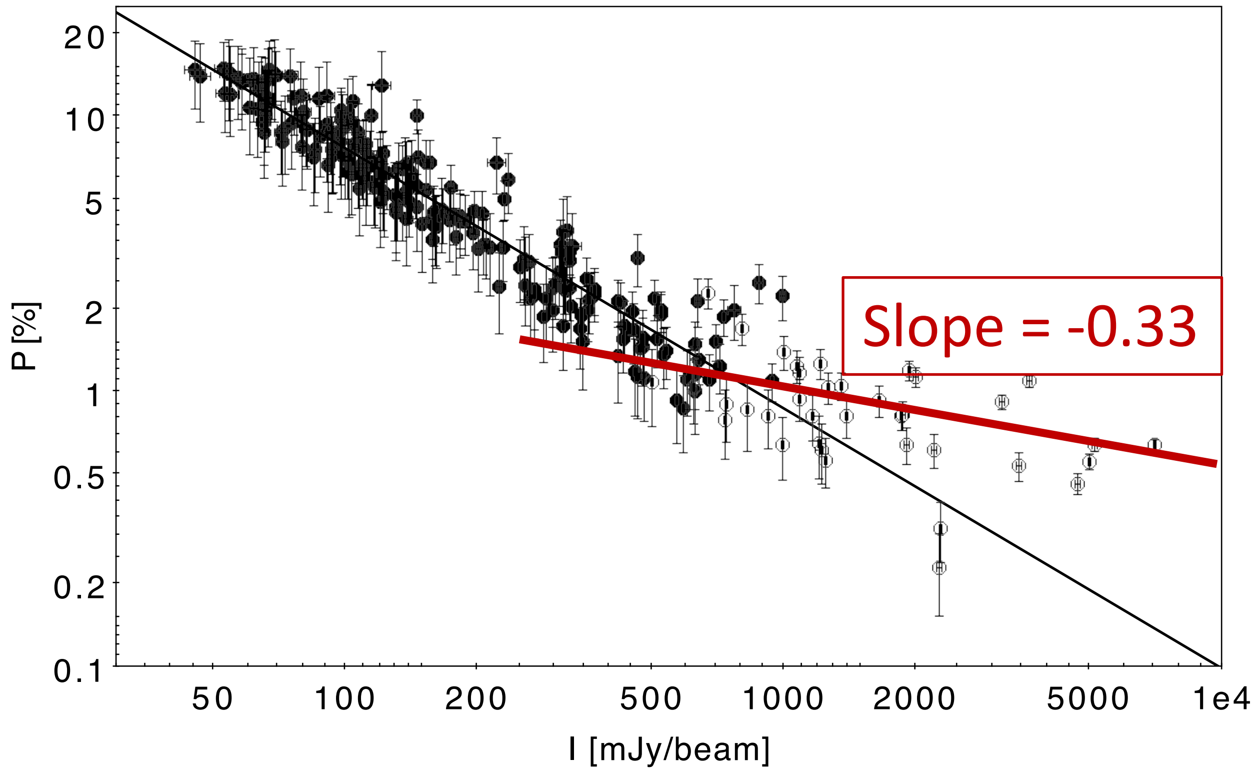


2. Polarization properties: depolarization

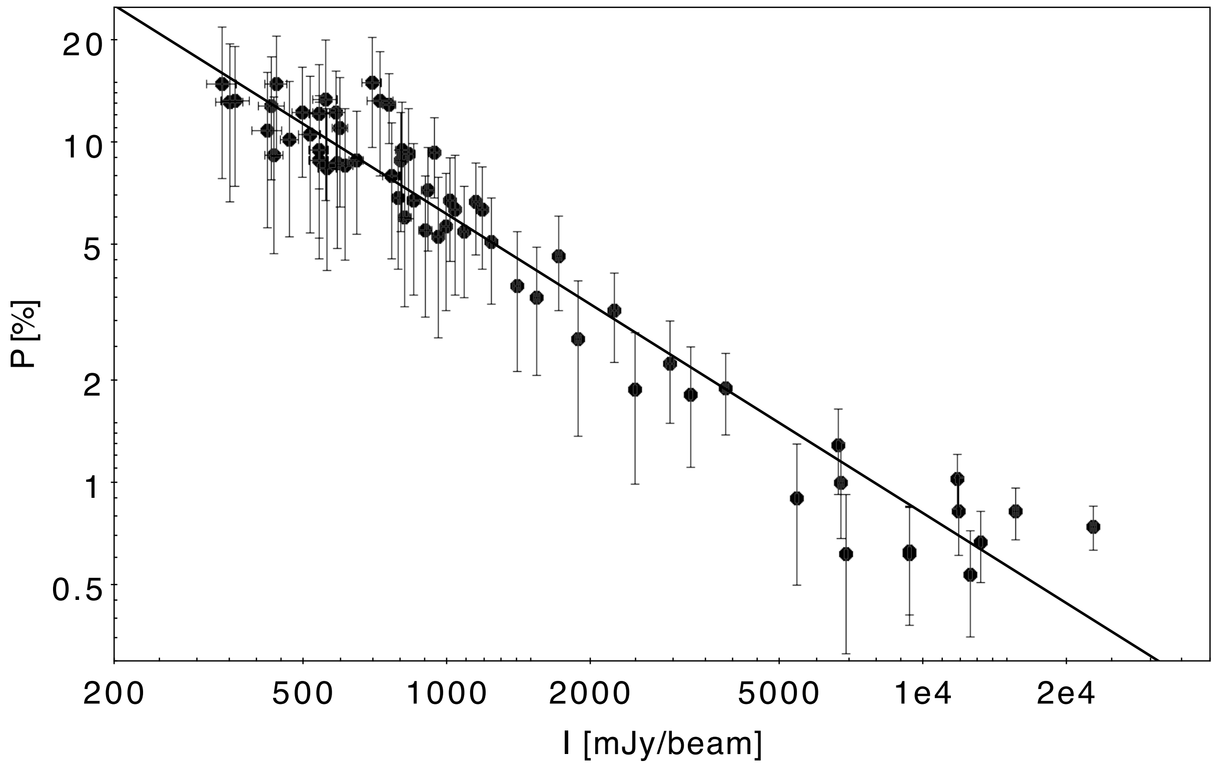
- **Grain growth**: slow decline (-0.33) at 850 μm at the center region

  ※ radiative torque alignment (Lazarian & Hoang 2007)

  : larger and cooler grains are more efficient in the grain alignment
- **geometrical effect**: $\langle P \rangle_{450\ \mu m, 9.6''} = 1.47\ \%$, $\langle P \rangle_{850\ \mu m, 14.1''} = 0.89\ \%$, at the center



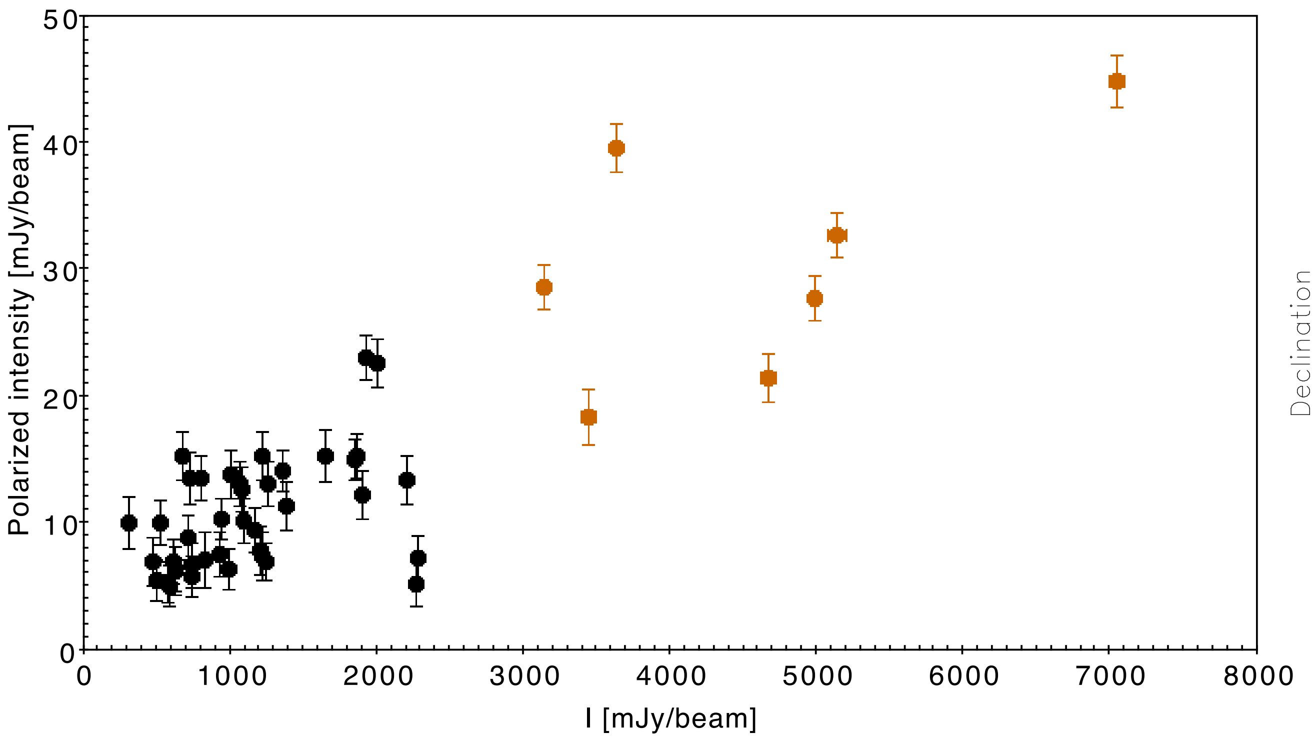
850 μm (250 vectors)

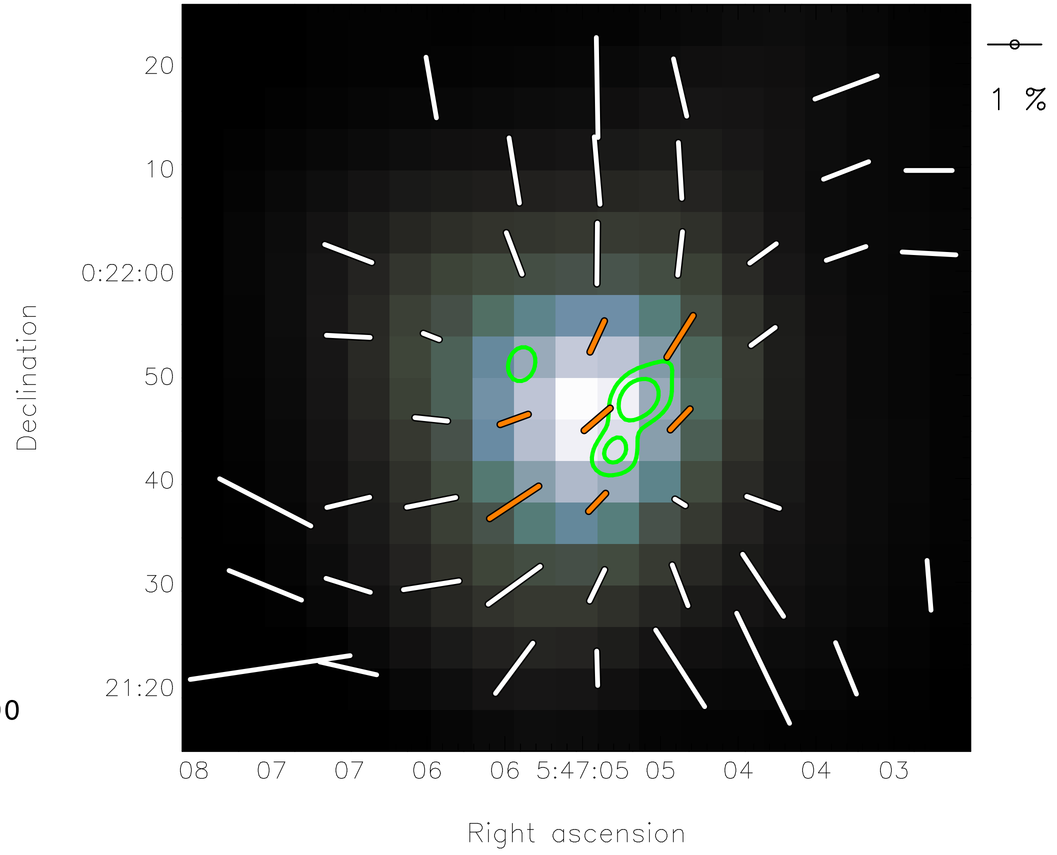


450 μm (62 vectors)

2. Polarization properties: depolarization

■ **Grain growth**: higher polarized intensity at the stronger intensity of I at 850 μm

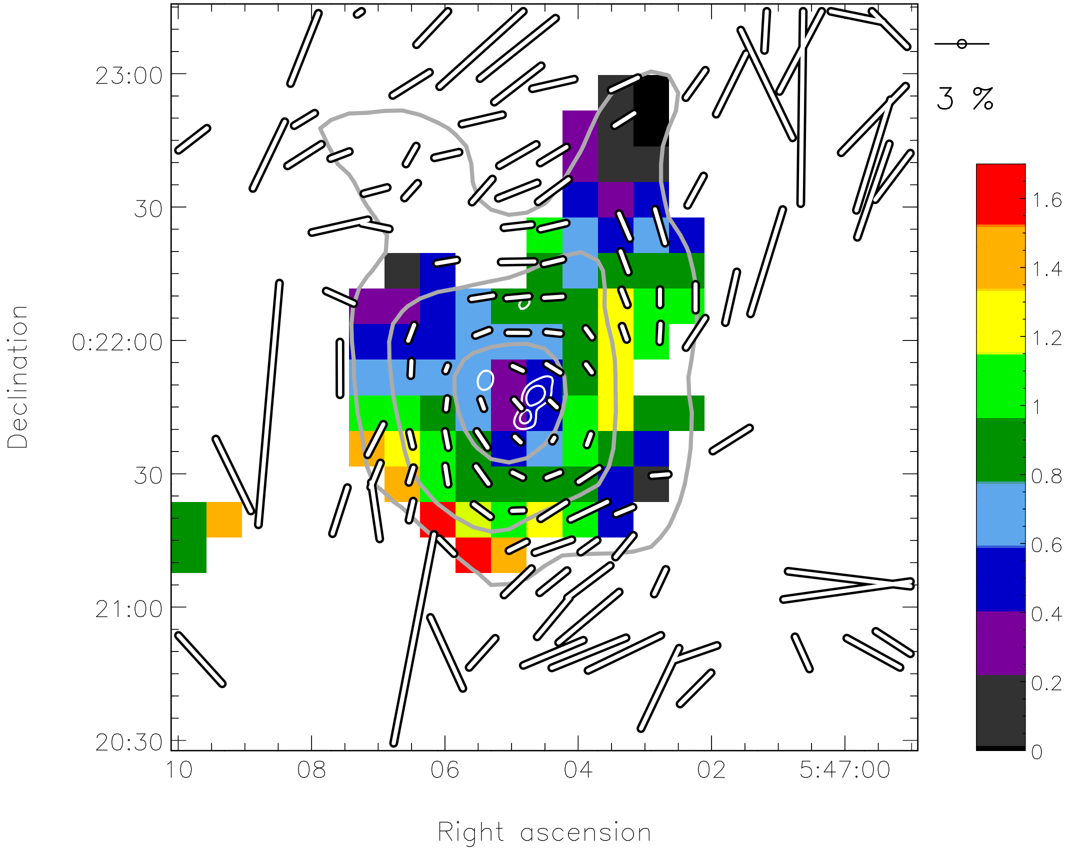


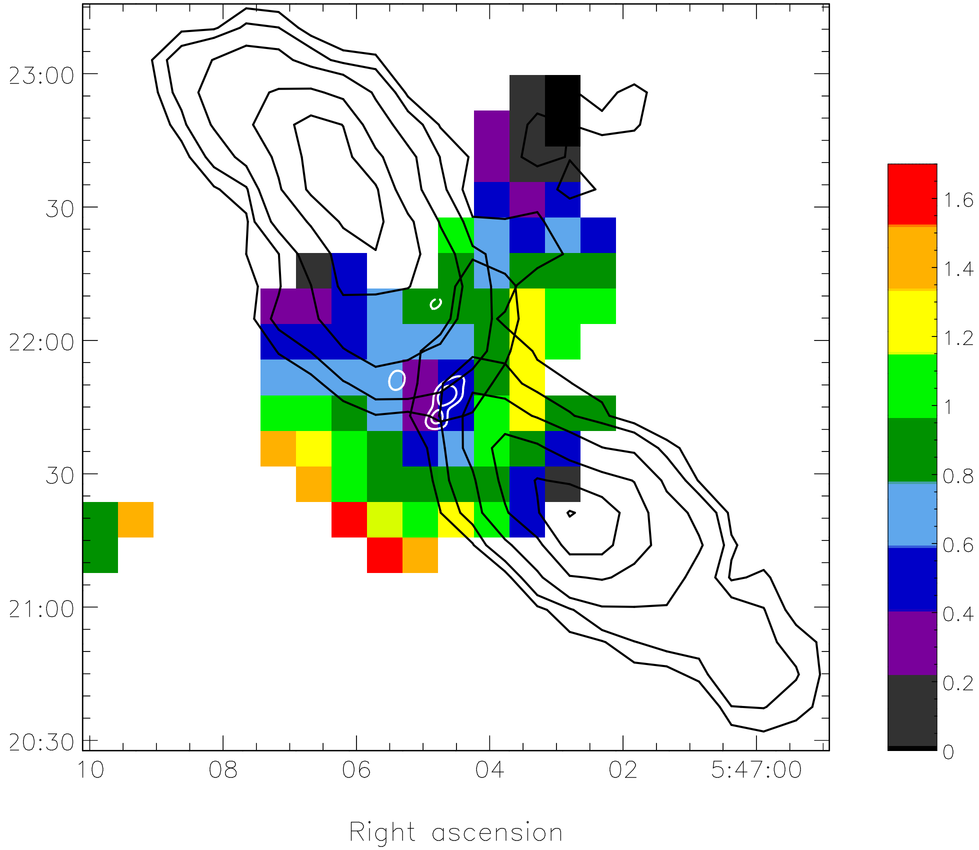


2. Polarization properties: depolarization

■ **Grain growth**: lower β (optical spectral index) value toward the center region

$$\frac{I_{\nu_{450\mu m}}}{I_{\nu_{850\mu m}}} = \frac{e^{\frac{h\nu_{850\mu m}}{kT}} - 1}{e^{\frac{h\nu_{450\mu m}}{kT}} - 1} \left(\frac{\nu_{450\mu m}}{\nu_{850\mu m}}\right)^{\beta+3}$$





Summary of the Polarization properties

(1) Pinched B-field structure at the center dense core region
: No evidence of hourglass B-field morphology, since there's no flattened structure

(2) Good polarization angle agreement in the center region at both 450/850 μm data
: supporting the validity of 450 μm polarization data

(3) Depolarization at both 450/850 μm with a slope of about **-1**

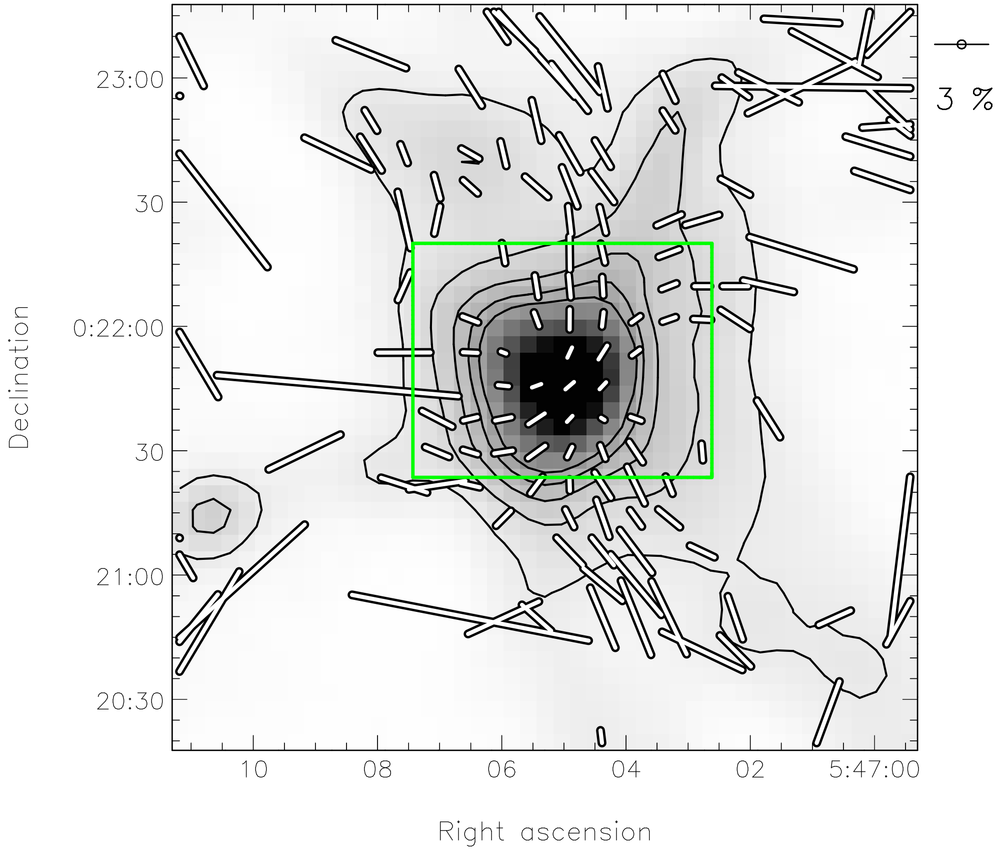
- ■ **grain growth** at the center region ?
  - slow decline at the center of 850 μm polarization data of slope = -0.33, while no trend at 450 μm data
  - higher polarized intensity at the stronger intensity
  - lower optical spectral index (β) at the center
- ■ **geometrical effect ?**
  : average polarization fraction at the center region: 1.47% (450 μm), 0.89%(850 μm)

3. B-field properties: B-field strength < gravity

B_{pos} = 0.52 mG

(plane-of-sky B-field strength derived by Chandrasekhar-Fermi method Crutcher et al. 2004)

- Angular dispersion = **14.5°** (using the unsharp masking method Pattle et al. 2017)
- FWHM velocity dispersion from $C^{18}O$ (3-2) after subtracting the thermal motion (0.2 km/s) = **0.75 km/s**
- Hydrogen volume density **= 0.98 x 10^6 /cm^3**



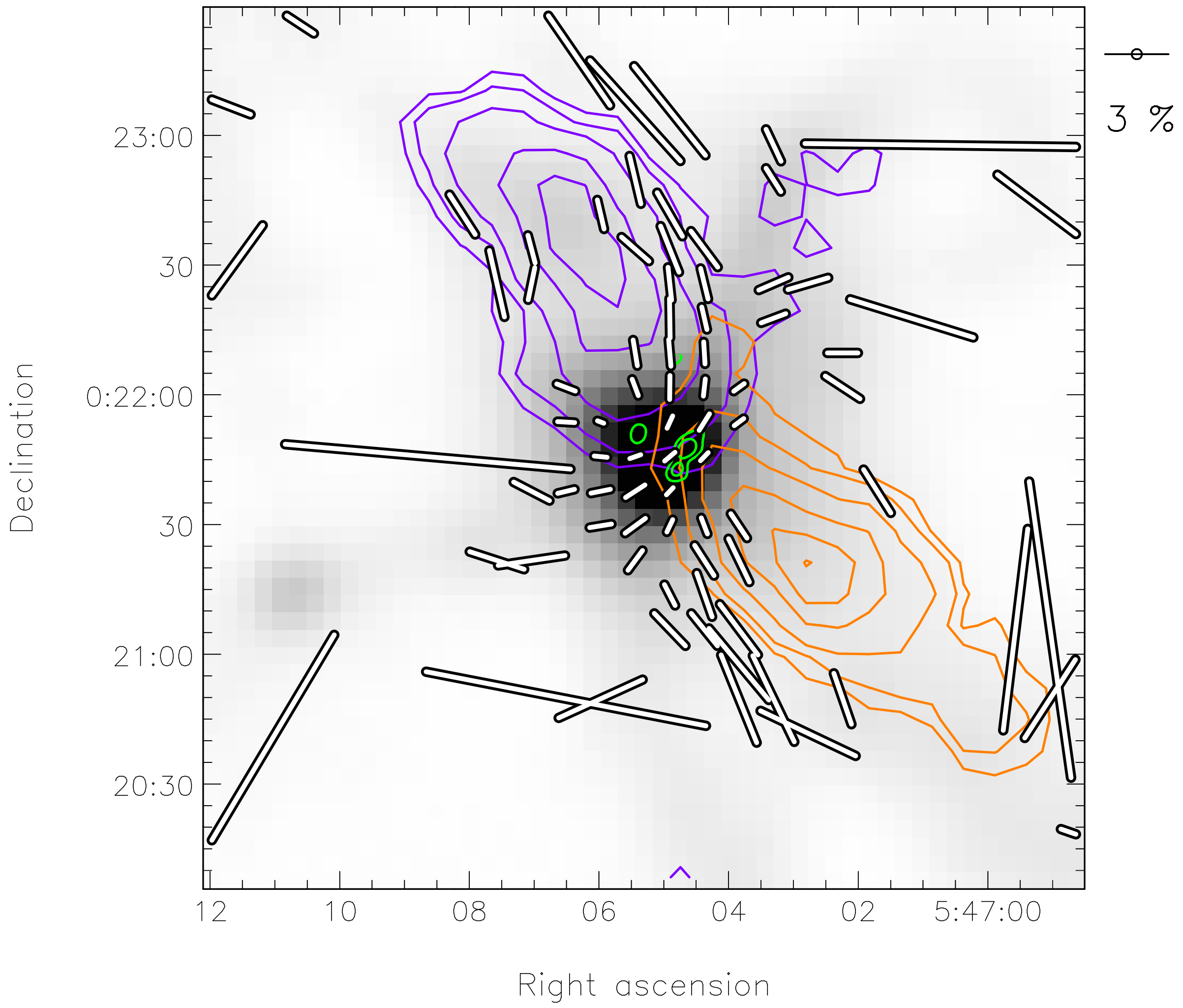
$$B_{pos} = Q\sqrt{4\pi\rho}\,\frac{\delta V}{\delta\phi} \approx 9.3\frac{\sqrt{n(H_2)}\Delta V}{\delta\phi}\ \mu G$$

$\lambda \equiv (\mathbf{M}/\mathbf{\Phi})_{obs} / (\mathbf{M}/\mathbf{\Phi})_{crit} \sim 1.2$

(slight gravitational collapse)

3. B-field properties: B-field strength < outflow

B-fields are well-aligned with the bipolar outflow



- $E_B \sim 5.1 \times 10^{37}$ J
- $E_K \sim 2.2 \times 10^{38}$ J
  (based on the $^{13}CO(3\text{-}2)$ emission)

- Outflow is shaping the B-field morphology

Summary of the B-field properties

- Strong B-field $\mathbf{B_{pos}}$ **= 0.52 mG** (10 times stronger than the result of Matthews et al. 2002)

- B-field are well-aligned with the bipolar outflow, following the cavity walls.

However,

(1) $\lambda \equiv \mathbf{(M/\Phi)_{obs} / (M/\Phi)_{crit}} \sim \mathbf{1.2}$
: gravity overcomes the resistance of the magnetic field

(2) $\mathbf{E_K > E_B}$: outflow shapes the magnetic field morphology